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Module 10

Hydrology for Plan Reviewers

Virginia Department of Environmental Quality

Plans approved after July 1, 2014 (except if grandfathered) LDA*:	Water Quantity Part II B Energy Balance + Flooding	Water Quality Part II B Runoff Reduction, Pollutant Removal
≥ 1 acre	✓	✓
≥ 10,000 ft.^{2}	✓	
≥ 2,500 ft.^{2} in CBPA	✓	✓

*May be more stringent (district or locality)

ESC vs SWM

Plan Reviewer for Stormwater Management

Water Quantity	Water Quality	Natural Processes
• Channel/Flood Protection *(9VAC25-870-66)* • Discharge • Volume • Duration	• Runoff Reduction Method *(9VAC25-870-63)* • Concentration • Volume • Load (mg/L * ft^3)	• Land Cover Types/Soils • Minimize impacts • Mimic (ESD) • Using Runoff Reduction Method

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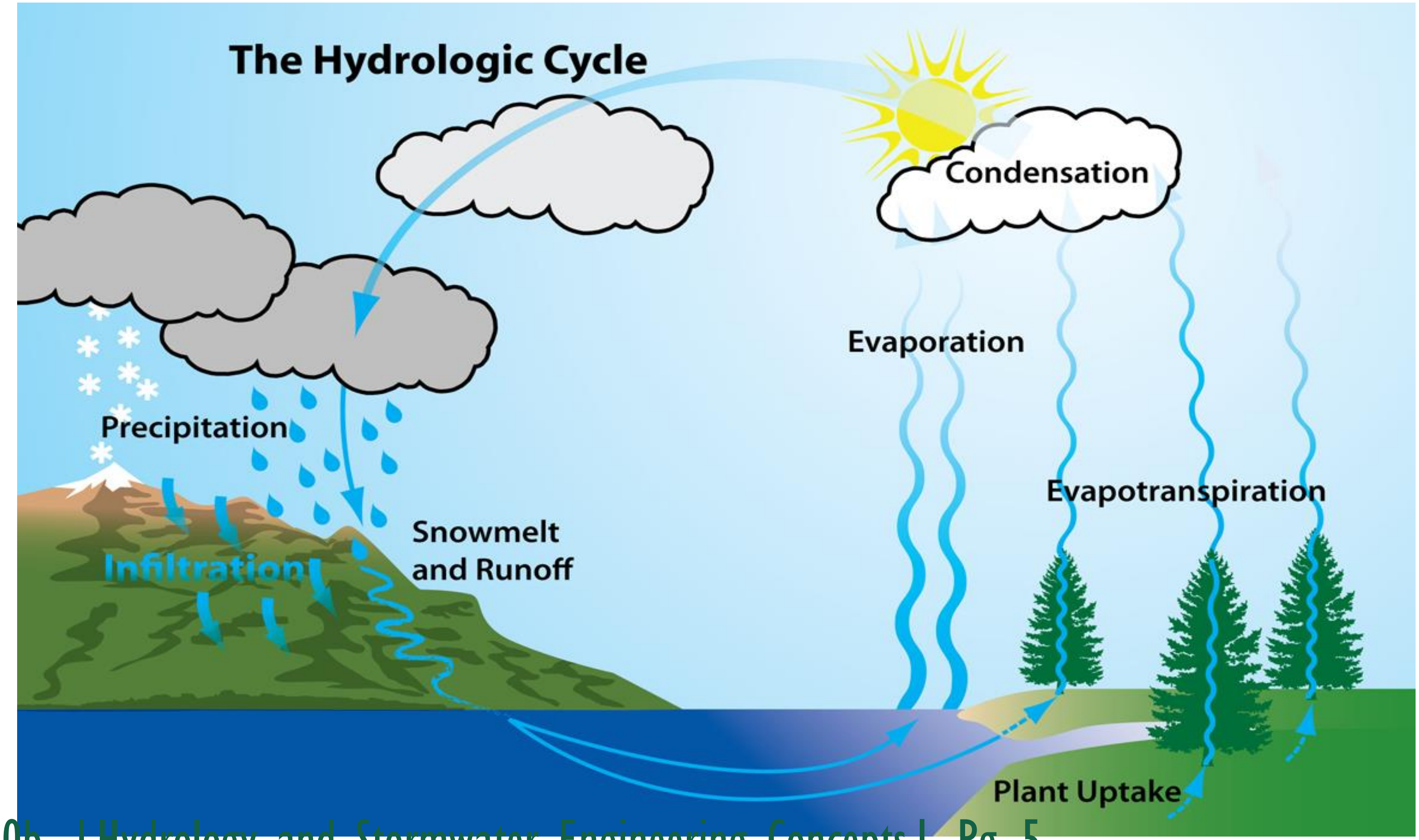
ESC vs SWM

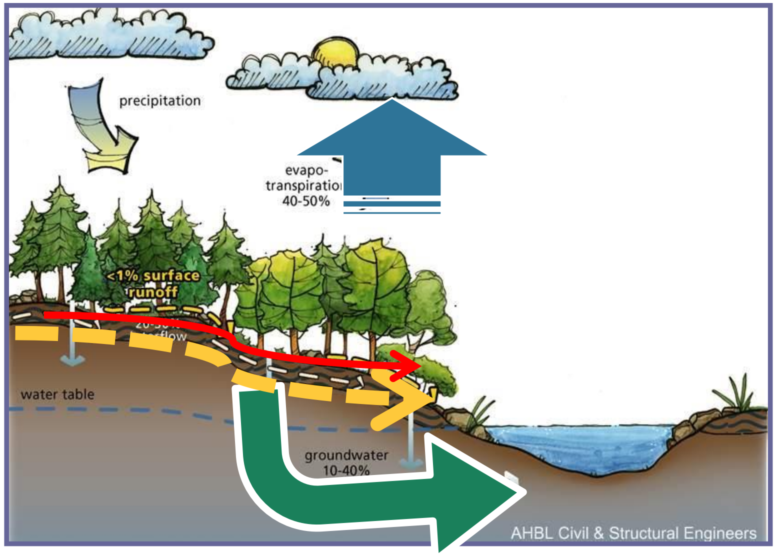
Plan Reviewer for Erosion & Sediment Control

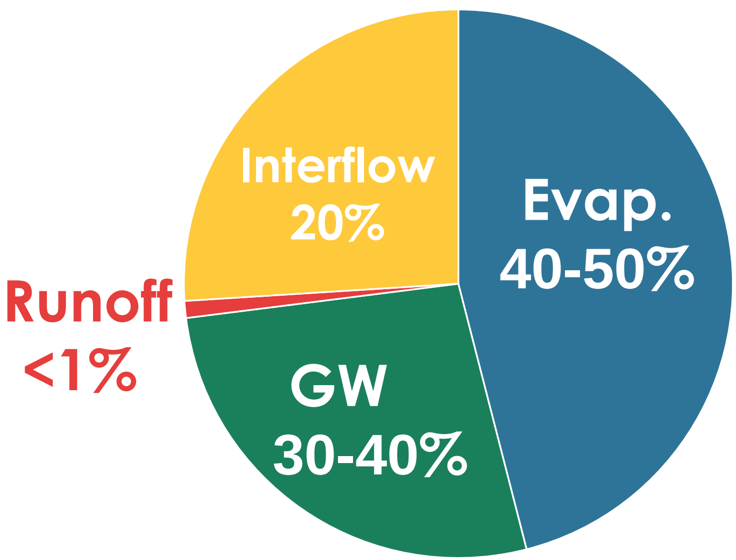
Water Quantity		Natural Processes
MS19: Channel/Flood Protection *(9VAC25-870-66)* Discharge Volume Duration	Energy Balance Equation Localized Flooding? Analyze to Limits of Analysis	• **Land Cover Types/Soils** • **Minimize impacts** • **Mimic (ESD)** • **Using Runoff Reduction Method**

Hydrologic Cycle

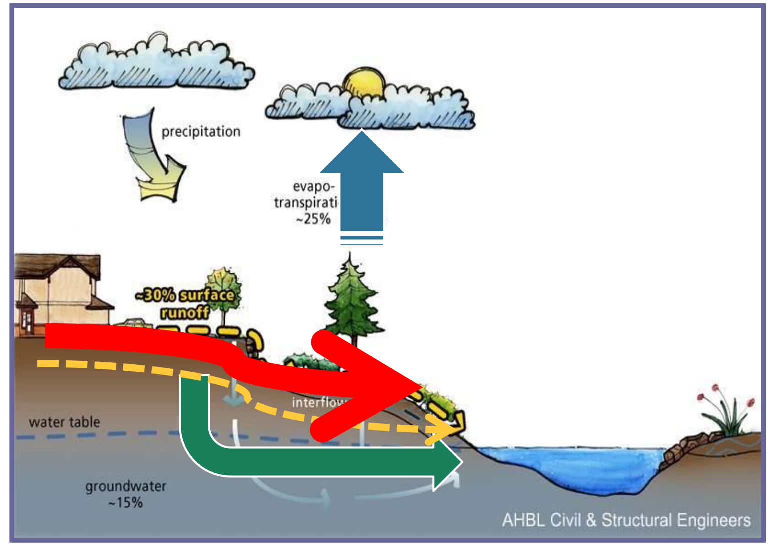


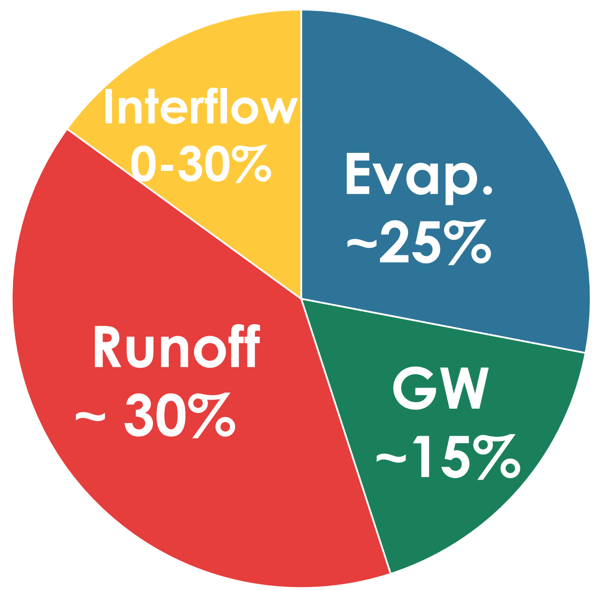
Pre-Developed Hydrology

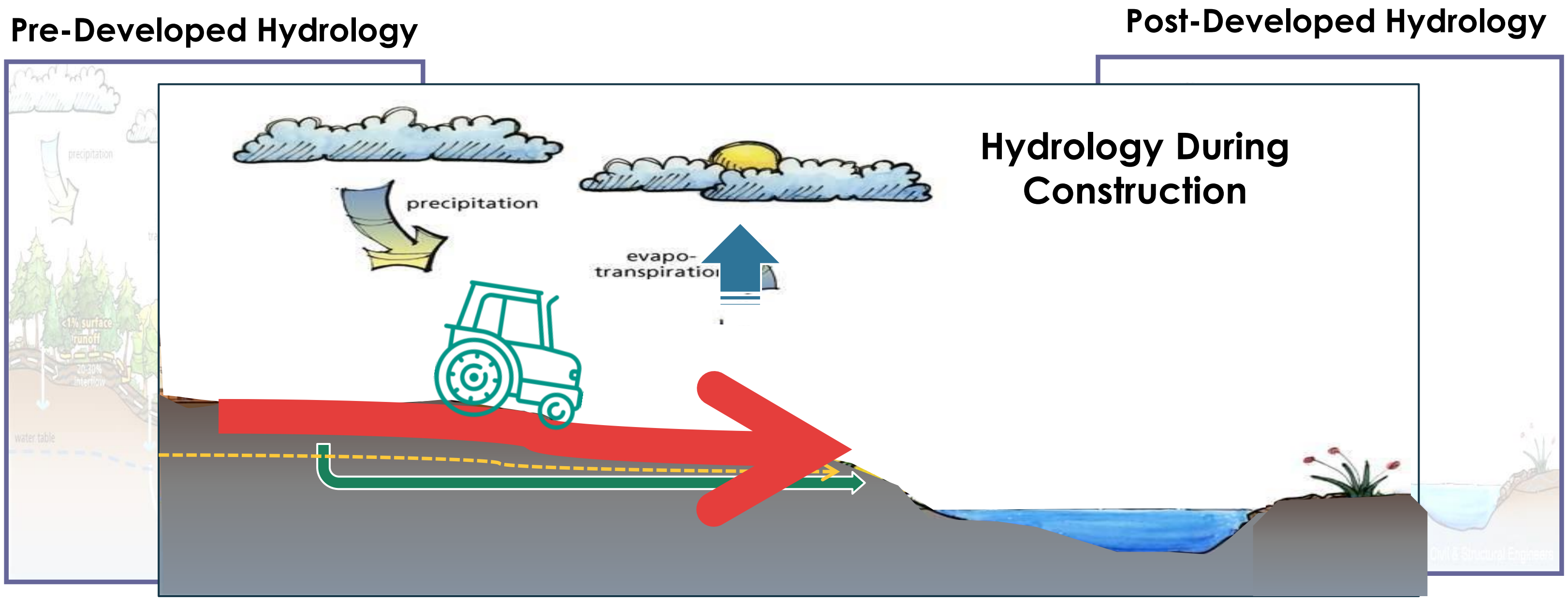


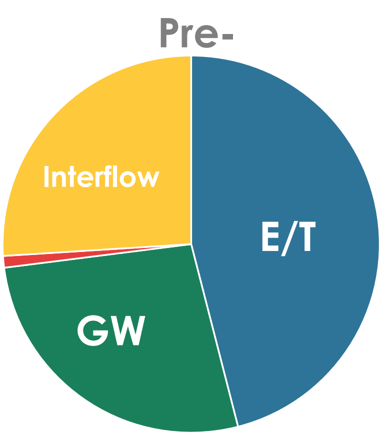


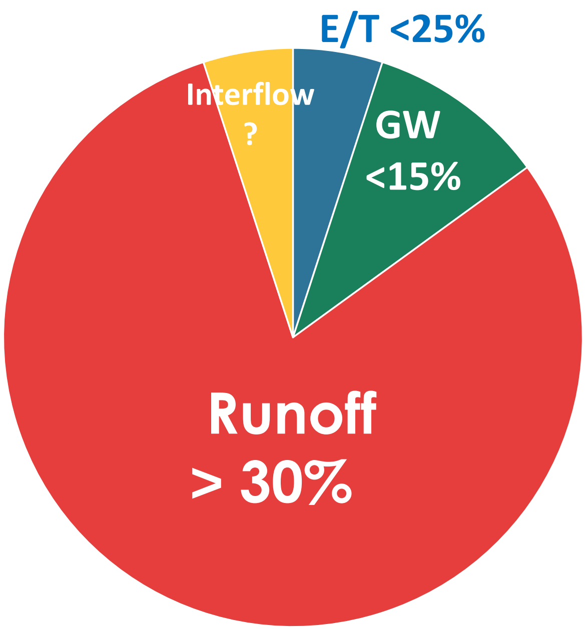
Post-Developed Hydrology

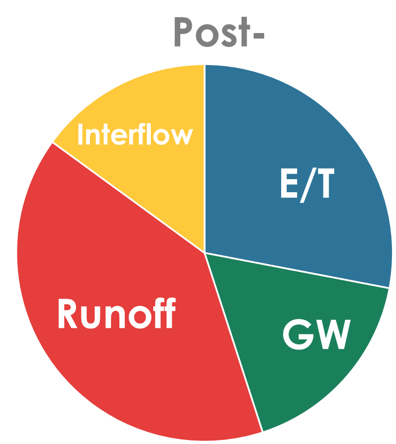





Pre-Developed Hydrology
Post-Developed Hydrology
Hydrology During Construction
precipitation
evapo-
transpiratio


Pre-
Interflow
E/T
GW


E/T <25%
Interflow
?
GW
<15%
Runoff
> 30%


Post-
Interflow
E/T
Runoff
GW

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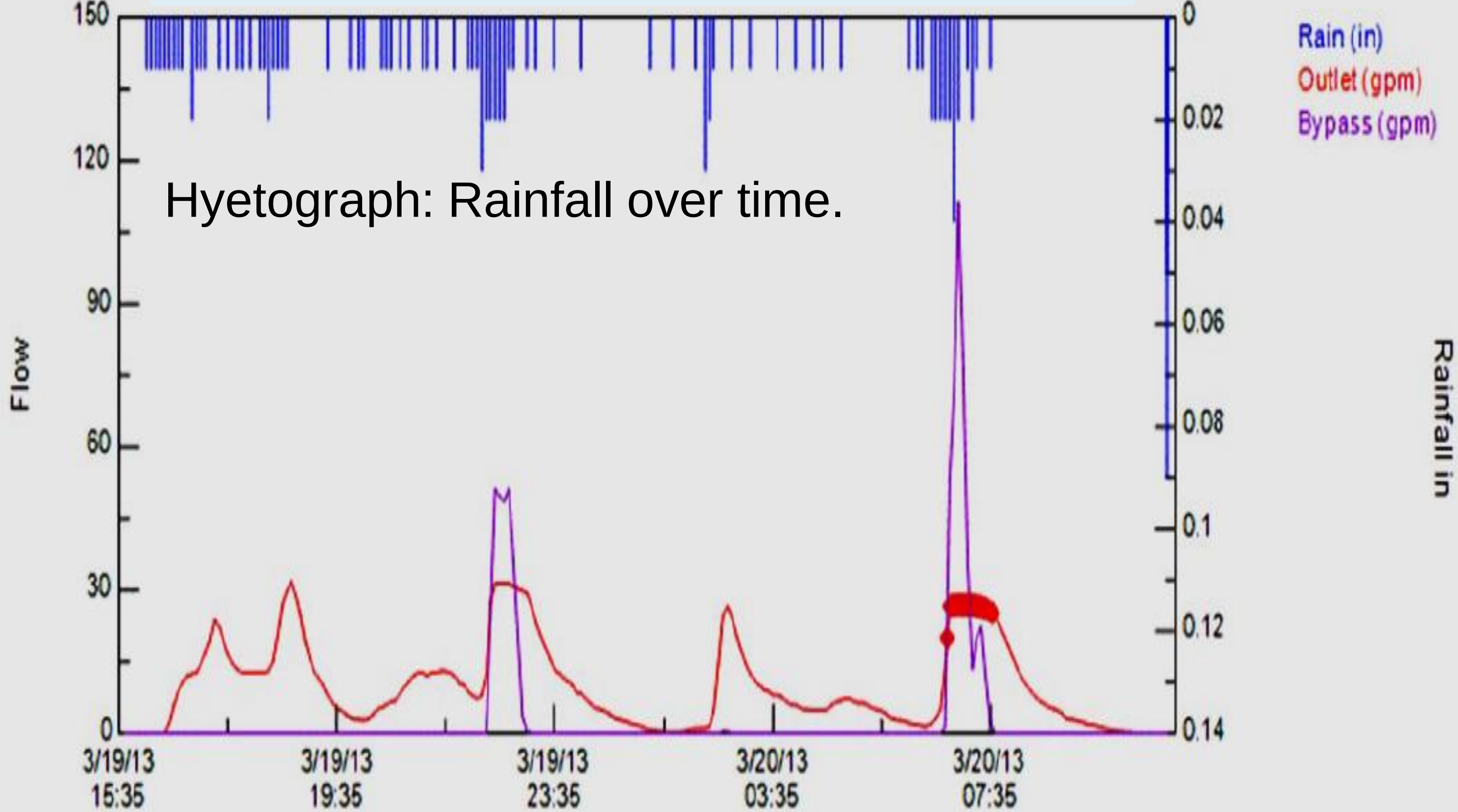
Watershed response to rainfall events: i.e **Rainfall-Runoff relationship**

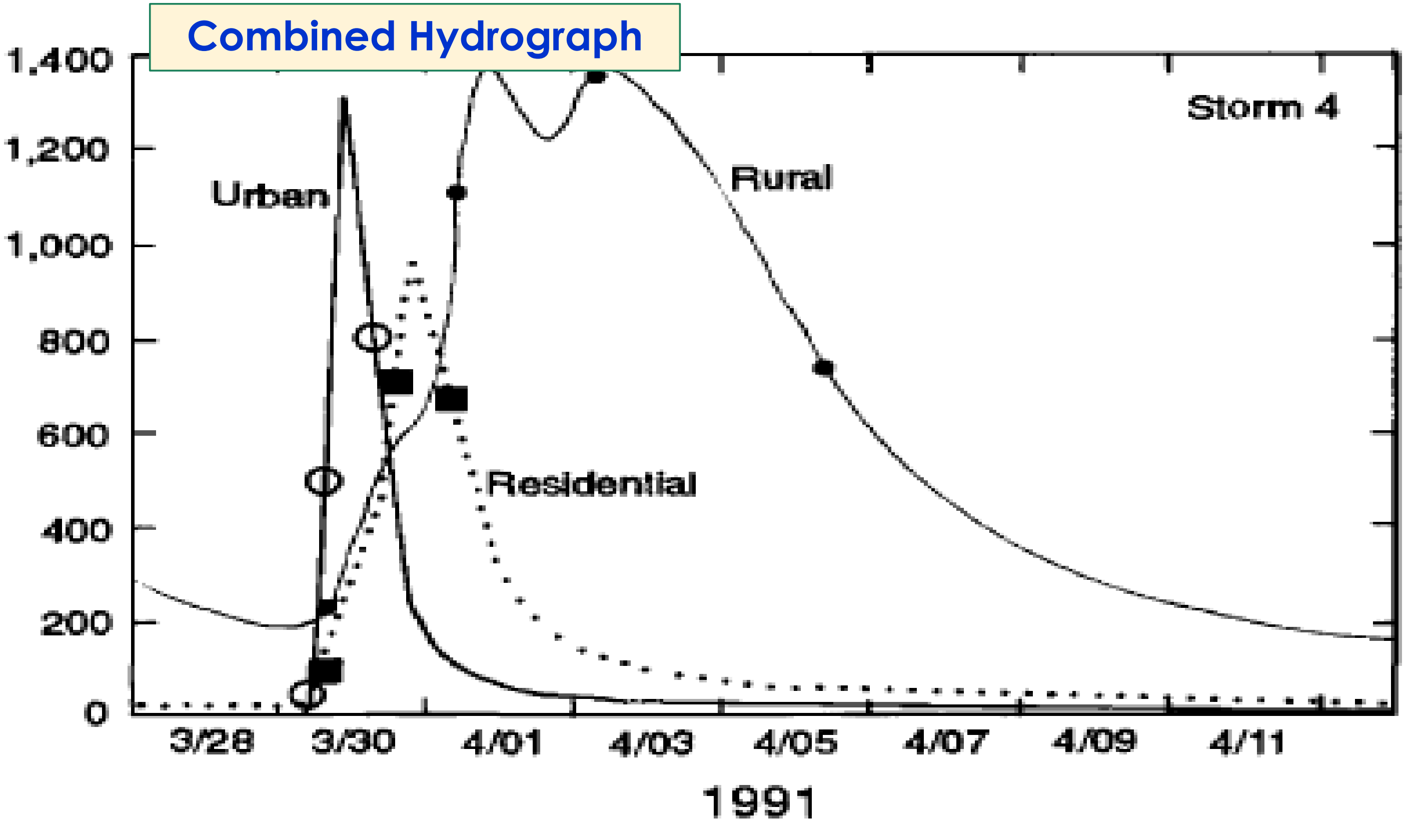
3/19/2013 Storm Event



Hyetograph: Rainfall over time.

Hydrograph: Flow or stage over time.

Rainfall-Runoff Relationships



Rainfall-Runoff Relationships

Ungauged watersheds

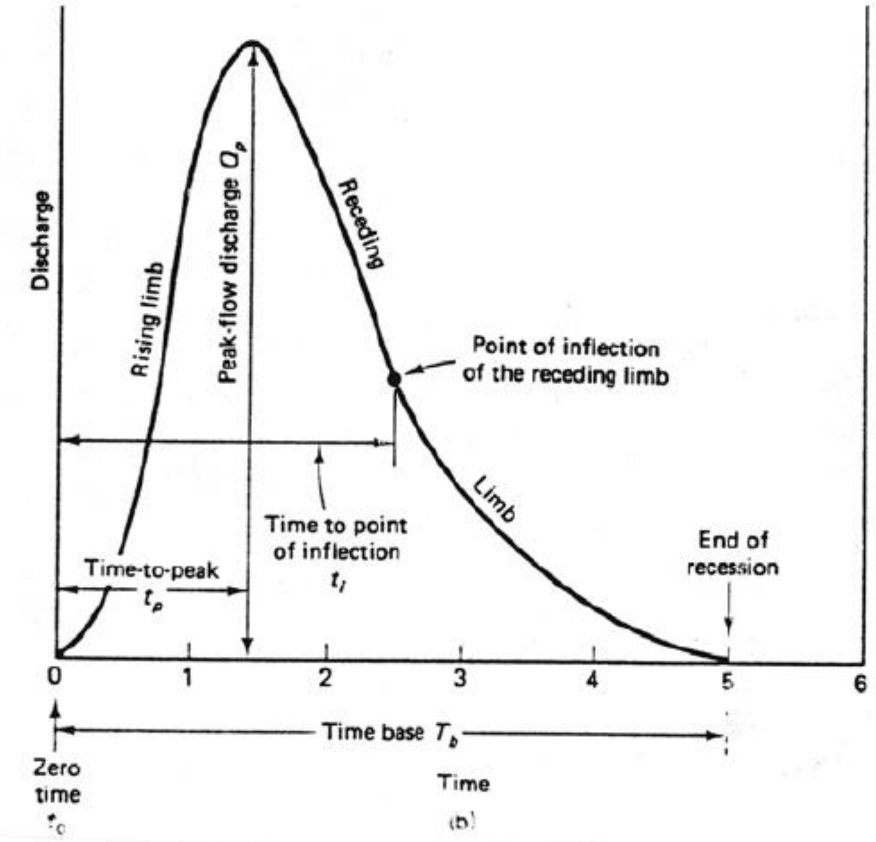
Create hydrographs by using synthetic methods

Impossible to collect at every discharge point of interest

Each method limited in specific runoff parameters it can provide

FIGURE 4 - 7

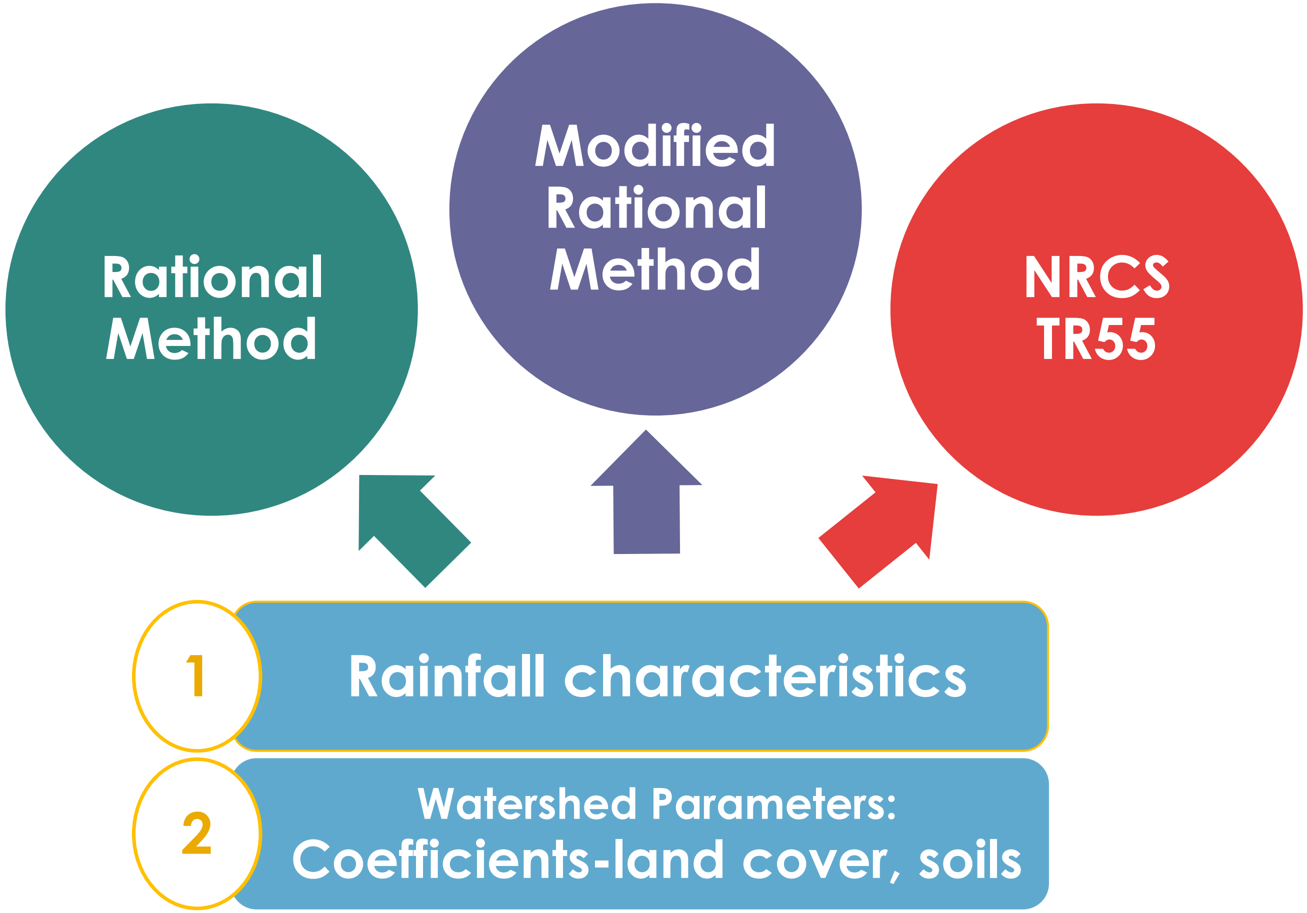
Runoff Hydrograph



1999 VA Stormwater Management Handbook Volume II

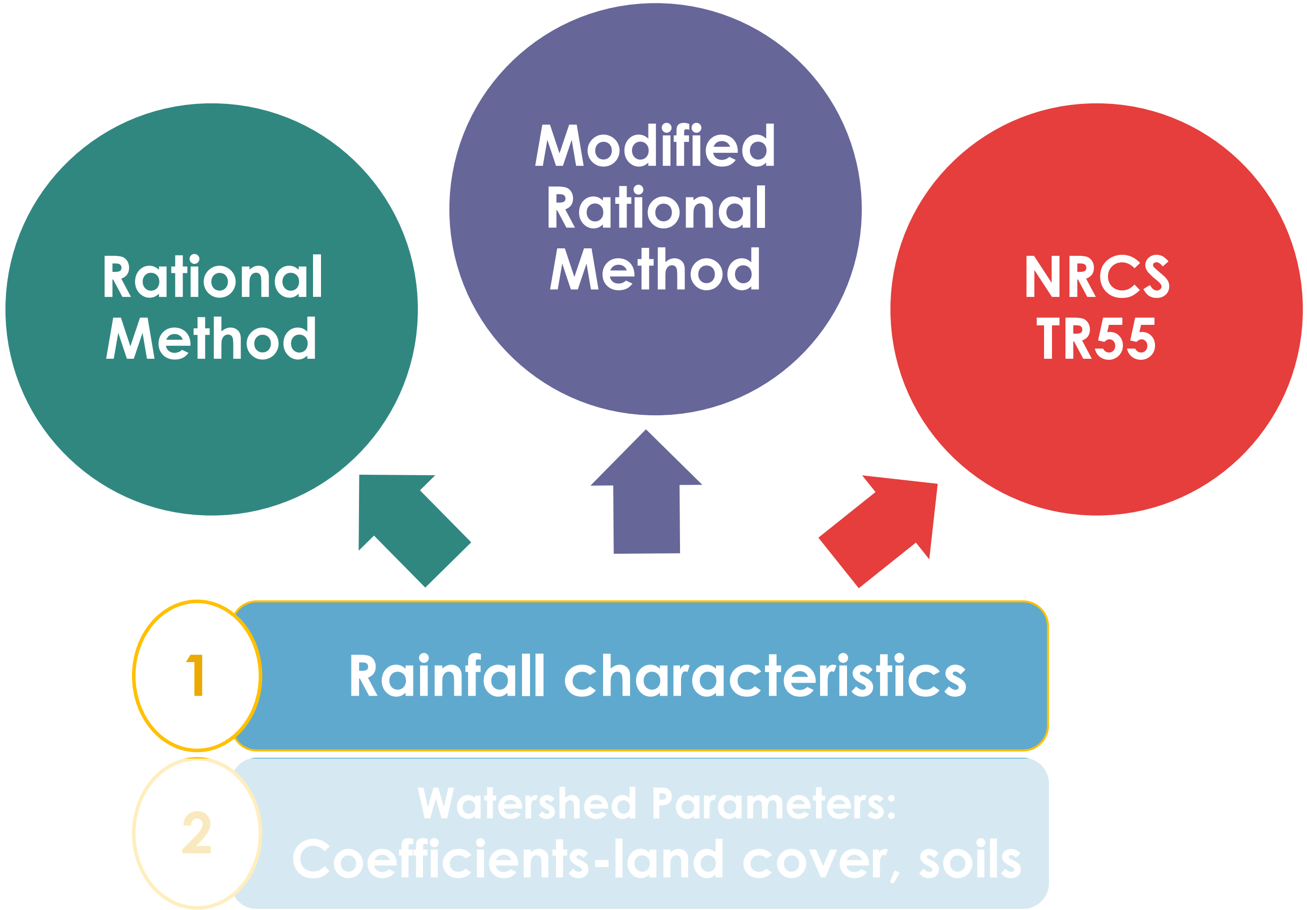
Individual projects sites: information never available

Estimate runoff with models



Individual projects sites: information never available

Estimate runoff with models



Precipitation

24-hr	Storm duration (units of time)
? inches	Storm depth (units of length)
? in/hr	Storm intensity (I) = depth(d) / time(t)
1-yr, 2-yr, 10-yr	Frequency (recurrence interval)
Type 2 or 3	Distribution

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Precipitation Frequency

Return Period (T) = 1/Probability (P)

Example:

100 year event = 1/100 or 0.01

or
1% chance of occurring
in any given year

Time of Concentration, Travel Time

Travel time (T_t):

Time it takes water to travel from one location to another in a watershed

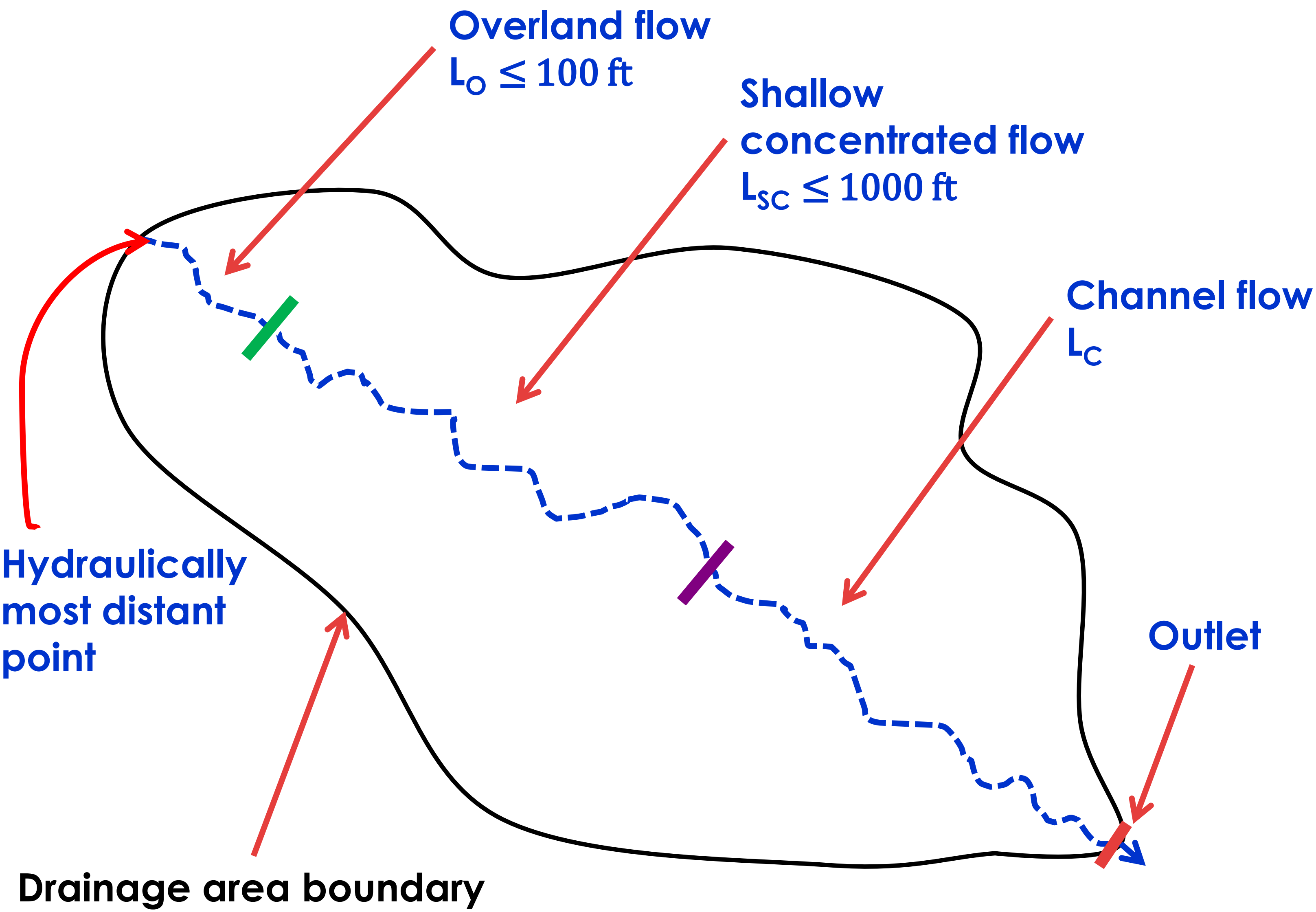
Time of concentration (T_c):

Time required for water to travel from most hydraulically distant point in watershed to point of analysis

(when whole watershed contributing runoff)

Sum of time increments for each flow segment

$T_c = \Sigma$ (overland flow + shallow concentrated flow + channel flow)


Overland flow
$L_O \leq 100$ ft
Shallow concentrated flow
$L_{SC} \leq 1000$ ft
Channel flow
L_C
Hydraulically most distant point
Outlet
Drainage area boundary

Time of Concentration, Travel Time

Flow segments

Overland (Sheet) Flow Manning's kinematic solution	Shallow flow	Upper reaches of hydraulic flow path
Shallow Concentrated Flow Graphical solution	Overland flow converges to form defined flow	Flow Paths w/o defined channel
Channel Flow Manning's Equation	Flow converges in natural or manmade conveyances	Well defined drainageway

Time of Concentration (Tc)

- *Computing Overland Flow*
  - Seelye Method
  - Kinematic Wave Method
  - NRCS Technical Release 55 (TR-55) Method

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Overland Flow: Seelye Method

- **Seelye Chart, Plate 5-1, *VESCH* page V-11**
  - Step 1: Find flow LENGTH on first axis
  - Step 2: Find CHARACTER OF GROUND on second axis
  - Step 3: Draw straight line between points identified in Steps 1 and 2 and extend line to PIVOT LINE
  - Step 4: Find PERCENT SLOPE on fourth axis
  - Step 5: Draw straight line connecting point where first line crosses PIVOT LINE through PERCENT SLOPE and extend to fifth axis
  - Step 6: Read INLET CONCENTRATION TIME where second line meets fifth axis

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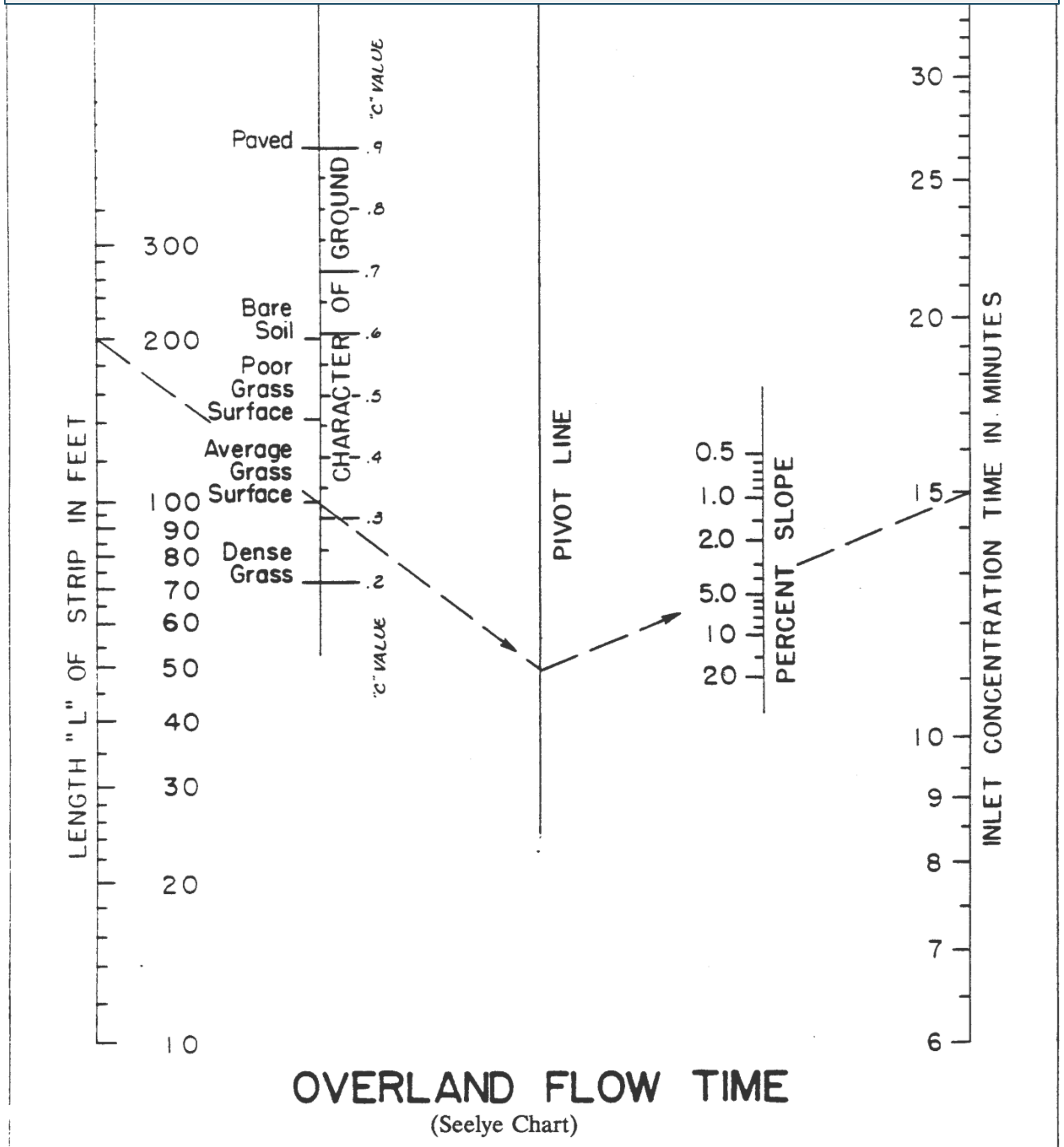
Seelye Chart, Plate 5-1, *VESCH* page V-11

- **Simplest method**
- **Small developments**



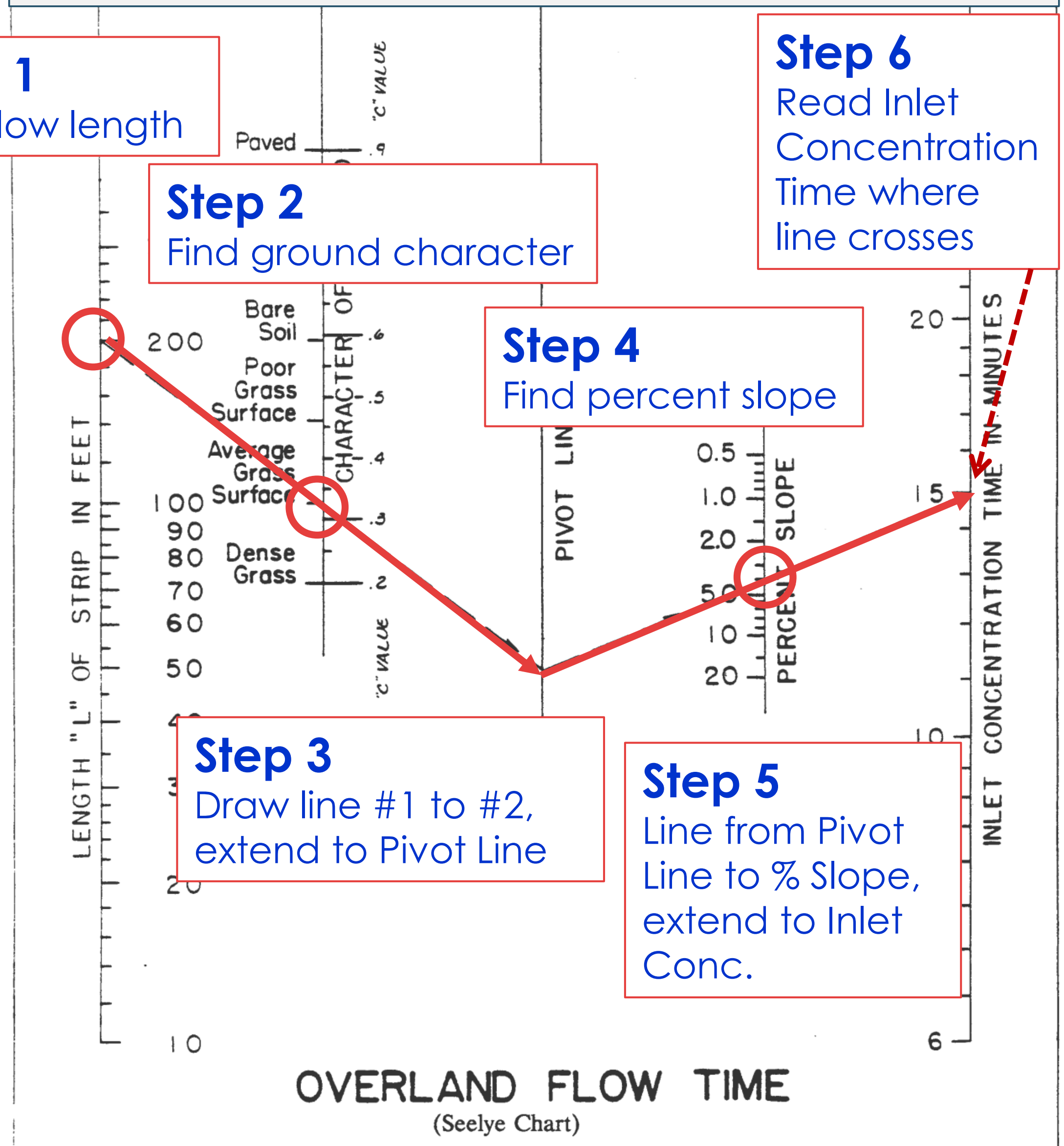
Example:

- 200 ft flow path
- Average Grass Surface ("C" value 0.32)
- 4% slope

Answer:

***Tt* = 15 minutes**

Seelye Chart, Plate 5-1, *VESCH* page V-11



Overland Flow: Kinematic Wave Model

- Allows input of rainfall intensity values
- Provides overland flow travel time for selected design storm
- Requires a "trial and error" approach

(equation includes 2 unknown variables)

Rainfall Intensity (*i*), Travel Time (*Tt*)

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Overland Flow: Kinematic Wave Model

$$Tt = 0.93 \times \frac{L^{0.6} \times n^{0.6}}{i^{0.4} \times S^{0.3}}$$

L **= length of overland flow (feet)**
n **= *Manning's* roughness coefficient (Table 5-7)**
i **= rainfall intensity (inches/hour) (Plates 5-4 to 5-18)**
S **= slope (feet/feet)**

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TABLE 5-7
ROUGHNESS COEFFICIENTS
(MANNING'S "n") FOR SHEET FLOW

Surface Description	n[1]
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover ≤ 20%	0.06
Residue cover > 20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses[2]	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods[3]:	
Light underbrush	0.40
Dense underbrush	0.80

1 The "n" values are a composite of information compiled by Engman (1986).

2 Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.

3 When selecting n, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

Source: USDA-SCS

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Overland Flow: NRCS TR-55 Method

$$Tt = 0.007 \times \frac{(nL)^{0.8}}{P_2^{0.5} \times s^{0.4}}$$

L **= length of overland flow (feet)**

n **= Manning's roughness coefficient**

P_2 **= 2 year, 24-hour rainfall in inches (NOAA Atlas 14)**

s **= slope (feet/feet)**

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Shallow Concentrated Flow: NRCS TR-55 Method

- Occurs where overland flow converges to form small rills, gullies, and swales
- Flow length 0 to 1000 feet maximum

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Shallow Concentrated Flow: NRCS TR-55 Method

$$Tt = \left(\frac{L}{V \times t} \right)$$

L **= flow length (feet)**

V **= average velocity (feet/second)**

t **= conversion factor**

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VESCH, Plate 5.2, p. V-12

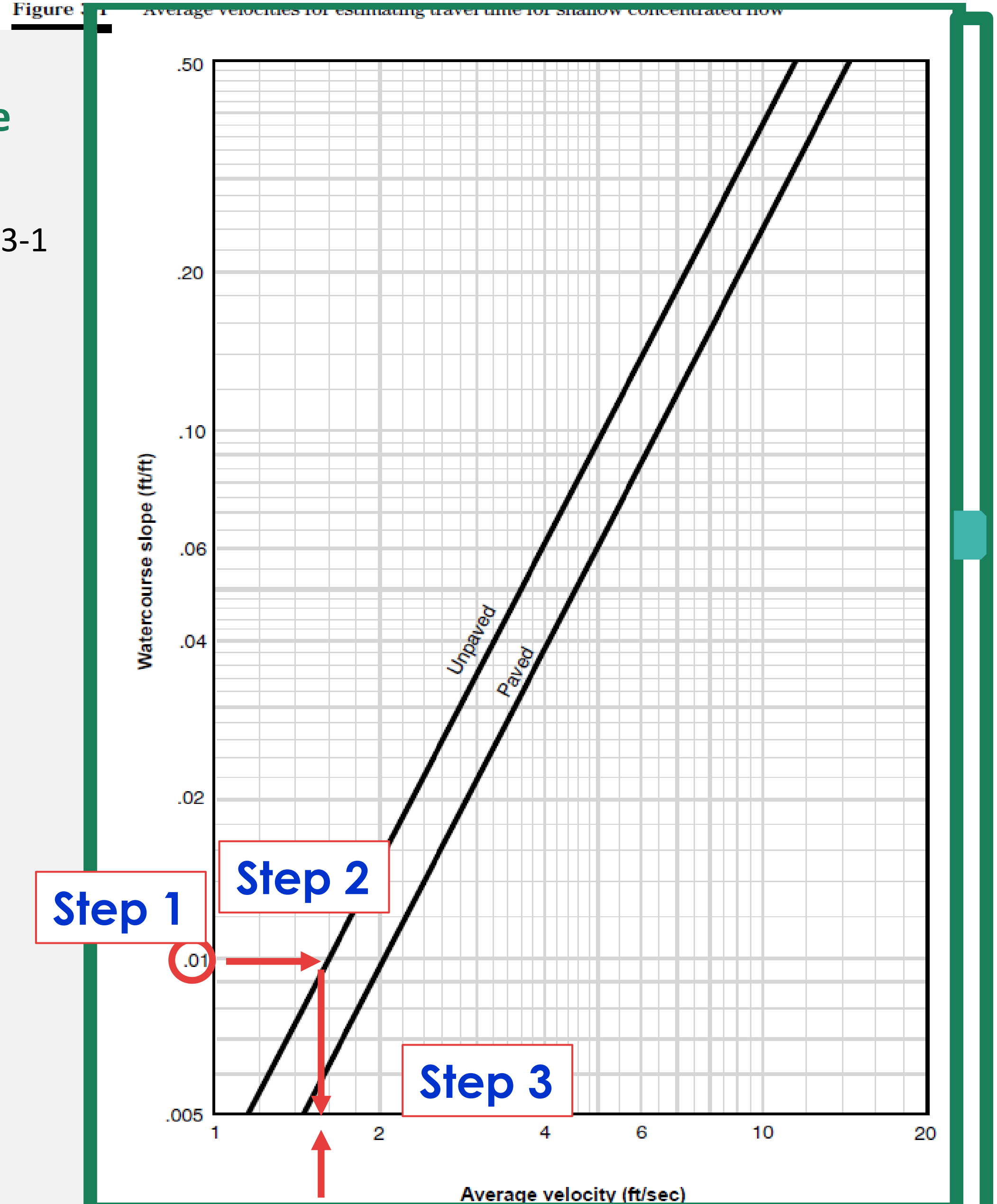
And TR-55, Fig. 3-1

Example:

- 1% slope (0.01 ft/ft)
- Unpaved
- Length = 200 ft

Answer:

- ✓ *V* = 1.6 ft/second
- ✓ *Tt* = 200/(1.6 x 60)
  = 2.1 minutes



Channel Flow

- Occurs where concentrated flow occurs in channels with well-defined cross-section (streams, ditches, gutters, pipes, etc.)
- Use velocity from Manning's equation for open channel flow:

$$V = \frac{1.49}{n} \times R^{(2/3)} \times \sqrt{s}$$

V = velocity (fps)
n = Manning's roughness coef.
R = hydraulic radius (A/P)
A= wetted cross sectional area
P=wetted perimeter(ft)
s = slope (ft/ft)

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Channel Flow

$$Tt = \left(\frac{L}{V}\right)$$

***L* = channel flow length** (feet)

***V* = average velocity**(feet/second)

→ ***use Manning's equation***

$$\boxed{V = \frac{1.49}{n} \times R^{(2/3)} \times \sqrt{s}}$$

Worksheet 3: Time of Concentration (T_c) or travel time (T_t)

Project	By	Date
Location	Checked	Date

Check one: ☐ Present ☐ Developed

Check one: ☐ T_c ☐ T_t through subarea

Notes: Space for as many as two segments per flow type can be used for each worksheet. Include a map, schematic, or description of flow segments.

SHEET FLOW (Tc only)

	Segment ID		
1.	Surface description (table 3-1)		
2.	Manning's roughness coefficient, n (table 3-1)		
3.	Flow length, L (total L † 300 ft) .... ft		
4.	Two-year 24-hour rainfall, P_2 .... in		
5.	Land slope, s .... ft/ft		
6.	$T_t = \frac{0.007\ (nL)^{0.8}}{P_2^{0.5}\ s^{0.4}}$ Compute T_t .... hr	+	=

SHALLOW CONCENTRATION FLOW

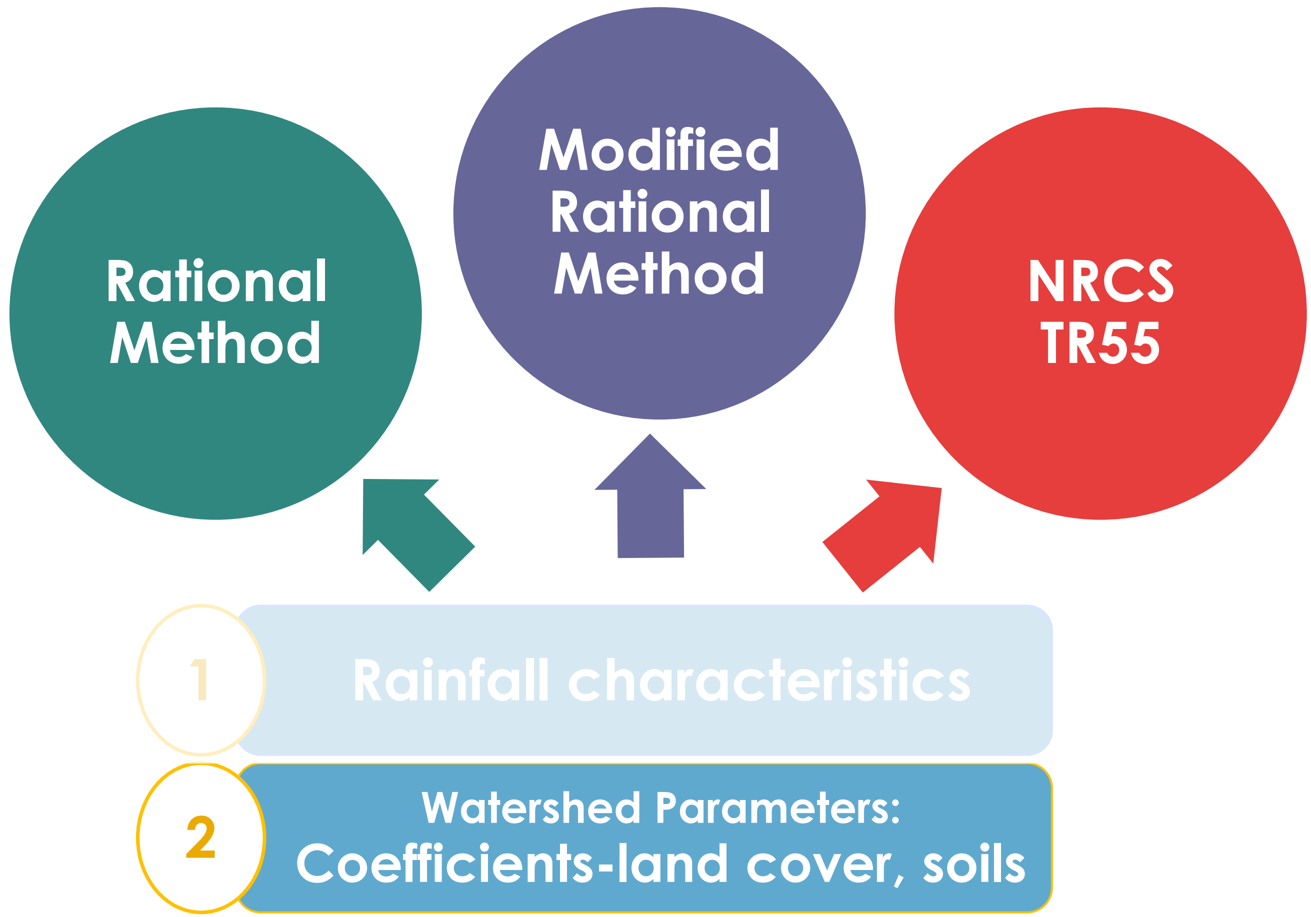
	Segment ID		
7.	Surface description (paved or unpaved)		
8.	Flow length, L ....ft		
9.	Watercourse slope, s .... ft/ft		
10.	Average velocity, V (figure 3-1) .... ft/s		
11.	$T_t = \frac{L}{3600\ V}$ Compute T_t .... hr	+	=

CHANNEL FLOW

	Segment ID		
12.	Cross sectional flow area, a .... ft^2		
13.	Wetted perimeter, p_w .... ft		
14.	Hydraulic radius, $r = \frac{a}{p_w}$ Compute r .... ft		
15	Channel slope, s .... ft/ft		
16.	Manning's roughness coefficient, n		
17.	$V = \frac{1.49\ r^{2/3}\ s^{1/2}}{n}$ Compute V ....ft/s		
18.	Flow length, L .... ft		
19.	$T_t = \frac{L}{3600\ V}$ Compute T_t .... hr	+	=
20.	Watershed or subarea T_c or T_t (add T_t in steps 6, 11, and 19) .... Hr		

Individual projects sites: information never available

Estimate runoff with models

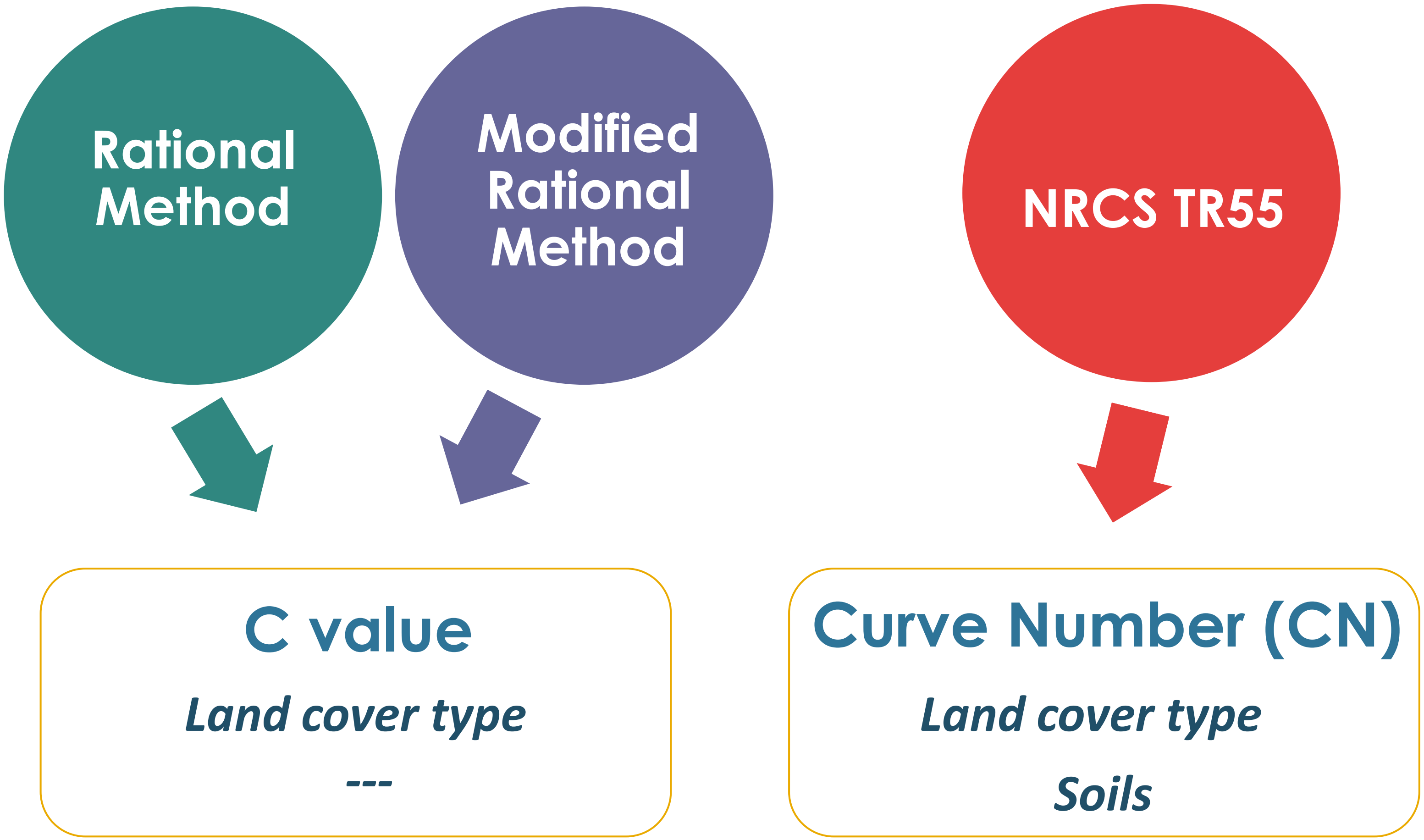


Rainfall-Runoff Coefficients

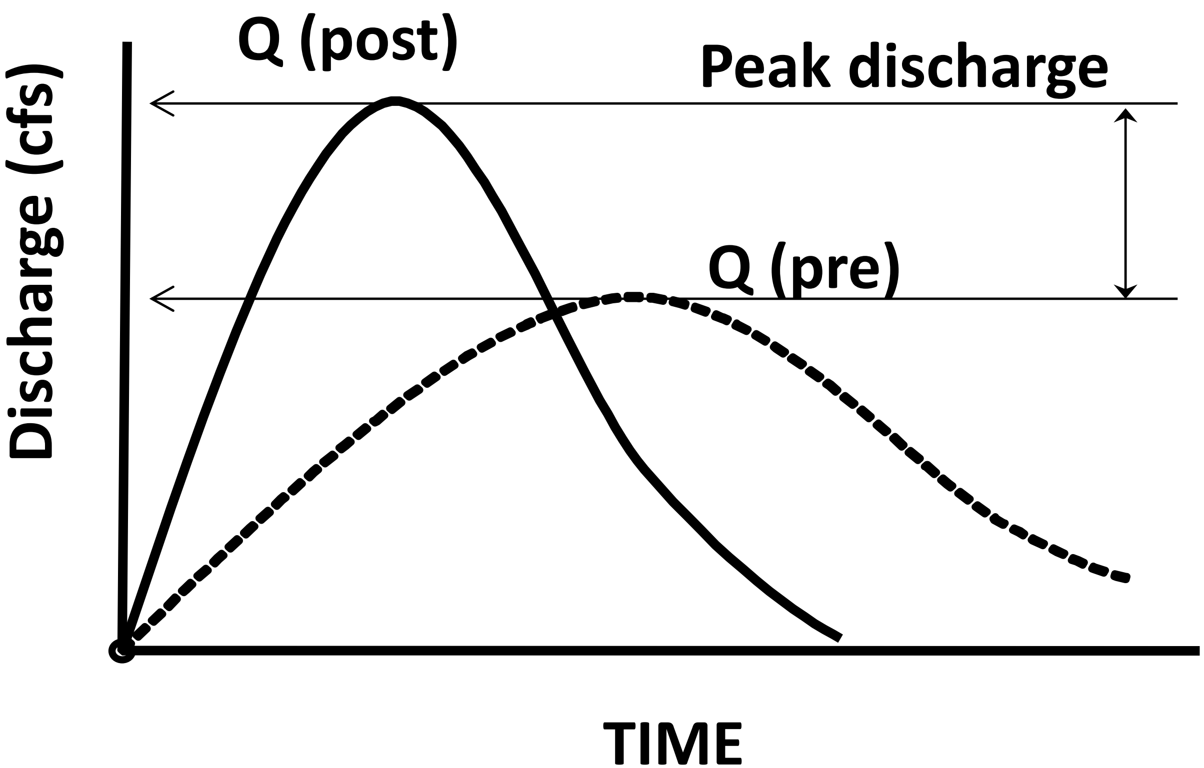
- Function of watershed response to rainfall event
- Includes watershed characteristics: slope, cover, soil type
- Individual project sites
  - Information never available
- Estimate with models
  - Runoff estimated from selected rainfall characteristics
  - Coefficients used to estimate runoff from rainfall intensities/amounts
- C value (Rational), Rv (Simple Method), CN (TR-55)
  - All take into account land cover types
  - Only CN and Rv account for soil types

Individual projects sites: information never available

Estimate runoff with models



Hydrographs



Graphical representation of discharge over time

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Rational Method

Rational Formula:

Estimates peak rate of runoff from drainage area

$$Q = C \times I \times A$$

Q = peak discharge (cfs)

C = runoff coefficient

I = average rainfall intensity (inches/hour)

A = drainage area (acres)

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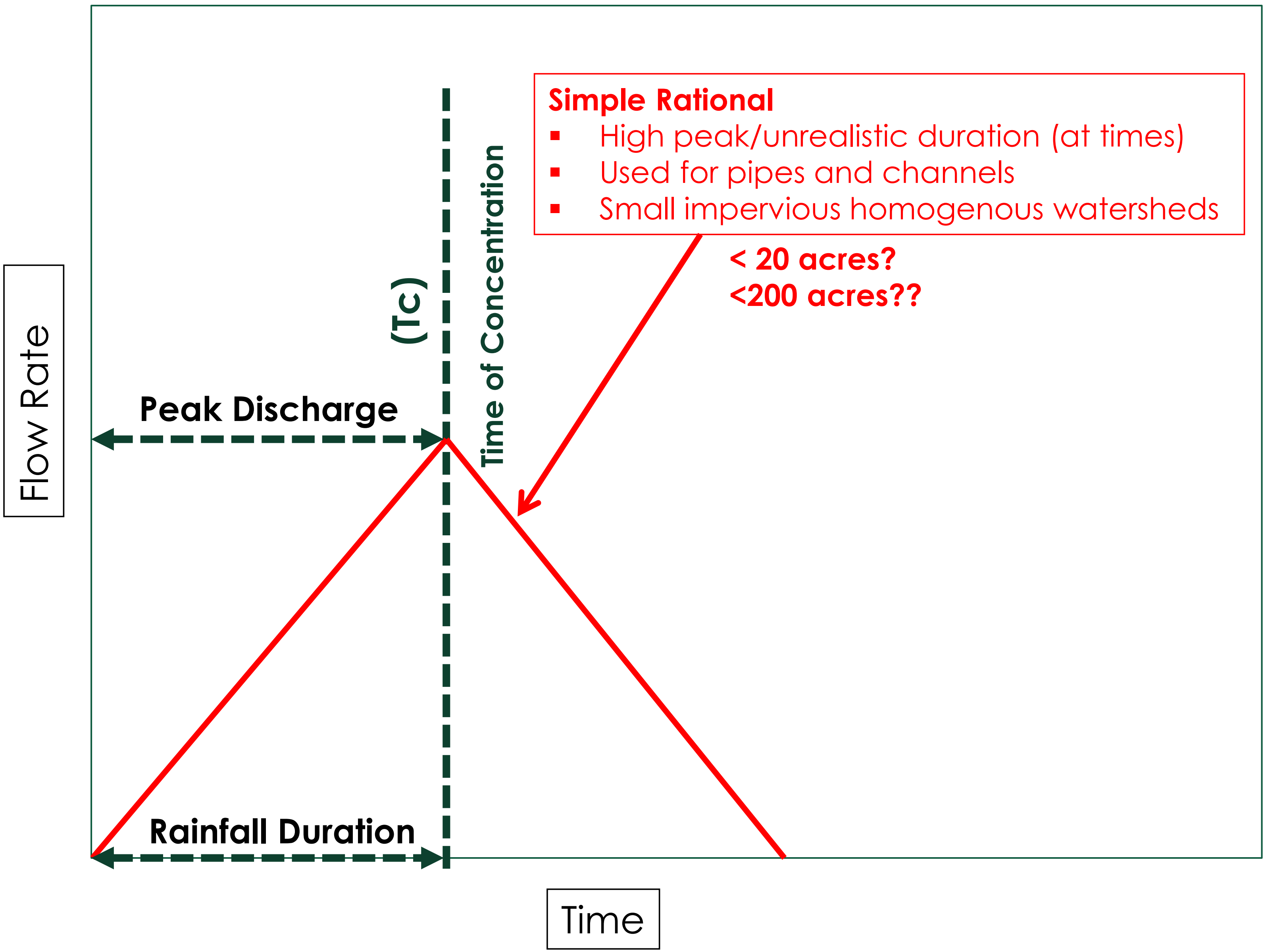
INFLOW HYDROGRAPHS



Rational Method

$$Q = C \times I \times A$$

Estimates peak rate of runoff from drainage area

- **Runoff Coefficient, C (0 to 1)**
  - Fraction of runoff for specific land cover type
  - Proportional to % impervious cover
  - Coefficients found in many publications including VESCH, p. V-29 Table 5-2)

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VESCH p. V-29 Table 5-2

TABLE 5-2
VALUES OF RUNOFF COEFFICIENT (C) FOR RATIONAL FORMULA

Land Use	C	Land Use	C
Business:		Lawns:	
Downtown areas	0.70-0.95	Sandy soil, flat, 2%	0.05-0.10
Neighborhood areas	0.50-0.70	Sandy soil, average, 2-7%	0.10-0.15
		Sandy soil, steep, 7%	0.15-0.20
		Heavy soil, flat, 2%	0.13-0.17
		Heavy soil, average, 2-7%	0.18-0.22
		Heavy soil, steep, 7%	0.25-0.35
Residential:		Agricultural land:	
Single-family areas	0.30-0.50	Bare packed soil	
Multi units, detached	0.40-0.60	* Smooth	0.30-0.60
Multi units, attached	0.60-0.75	* Rough	0.20-0.50
Suburban	0.25-0.40	Cultivated rows	
		* Heavy soil, no crop	0.30-0.60
		* Heavy soil, with crop	0.20-0.50
		* Sandy soil, no crop	0.20-0.40
		* Sandy soil, with crop	0.10-0.25
		Pasture	
		* Heavy soil	0.15-0.45
		* Sandy soil	0.05-0.25
		Woodlands	0.05-0.25
Industrial:		Streets:	
Light areas	0.50-0.80	Asphaltic	0.70-0.95
Heavy areas	0.60-0.90	Concrete	0.80-0.95
		Brick	0.70-0.85
Parks, cemeteries	0.10-0.25	Unimproved areas	0.10-0.30
Playgrounds	0.20-0.35	Drives and walks	0.75-0.85
Railroad yard areas	0.20-0.40	Roofs	0.75-0.95

Note: The designer must use judgement to select the appropriate "C" value within the range. Generally, larger areas with permeable soils, flat slopes and dense vegetation should have the lowest C values. Smaller areas with dense soils, moderate to steep slopes, and sparse vegetation should be assigned the highest C values.

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Rational Method: Runoff Coefficient (C)

- Drainage area with multiple land uses with different C values, weighted C value can be calculated

Example:

10.0 acre drainage area with 2 different land uses

- 2 acres of parking lot (C = 0.95) and
- 8 acres of park (C = 0.25)

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Rational Method: Runoff Coefficient (C)

- Calculate (C x A) value for each land use:

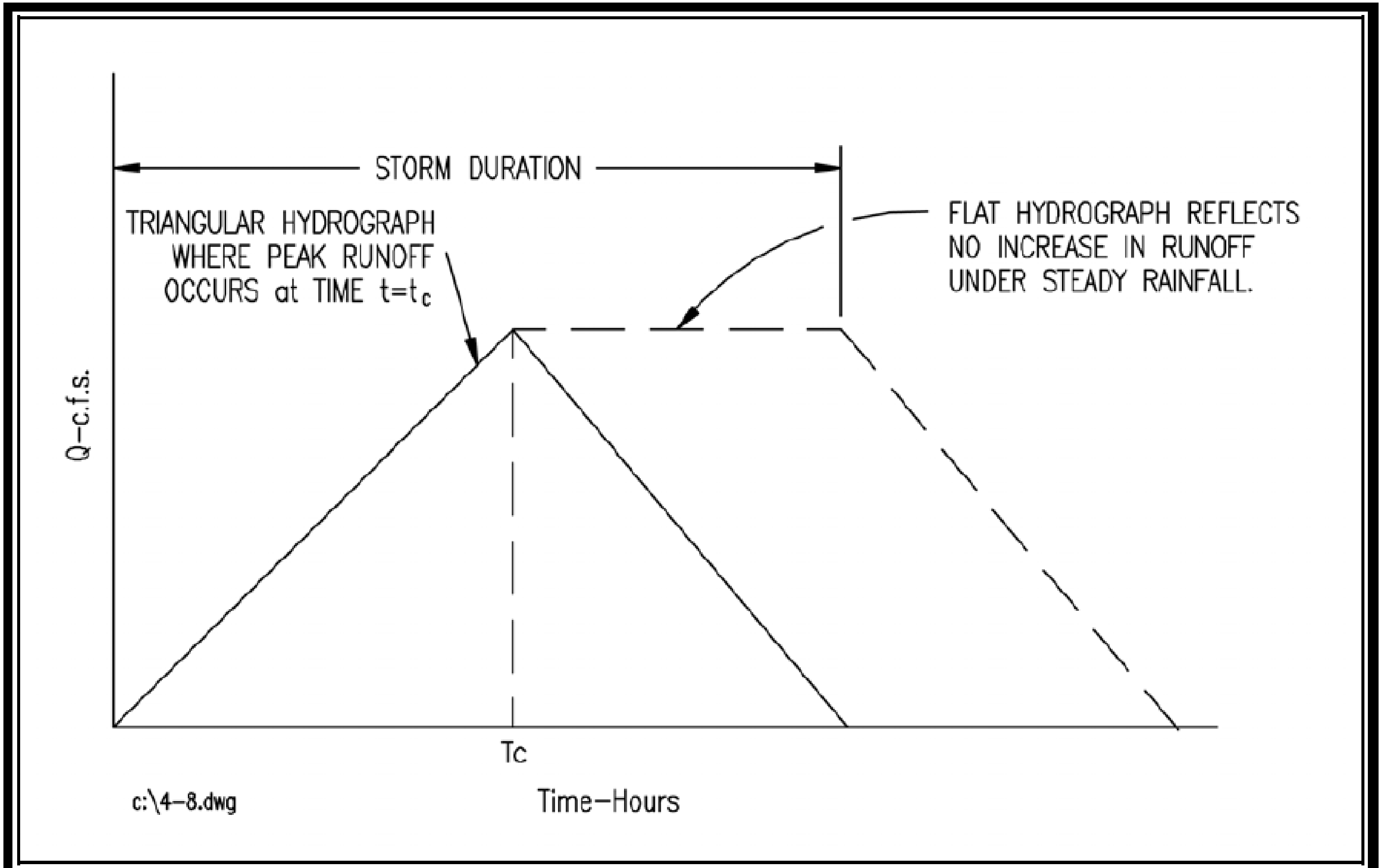
  C_{lot} **x** A_{lot} **= 0.95 x 2 = 1.9**

  C_{park} **x** A_{park} **= 0.25 x 8 = 2.0**

- Add (C x A) values together and divide sum by total area:

  (1.9 + 2.0)/10 = 3.9/10 = 0.39 = weighted C

FIGURE 4 - 8
Rational Method Runoff Hydrograph



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Rational Method

$$Q = C \times I \times A$$

Estimates peak rate of runoff from drainage area

- **Rainfall Intensity, I**
  - Rainfall intensity (in/hr) for storm duration = time of concentration (Tc)
  - Select proper ***Intensity-Duration-Frequency (IDF)*** curve *(VESCH, p. V-14 to V-28, Plates 5-4 to 5-18)*

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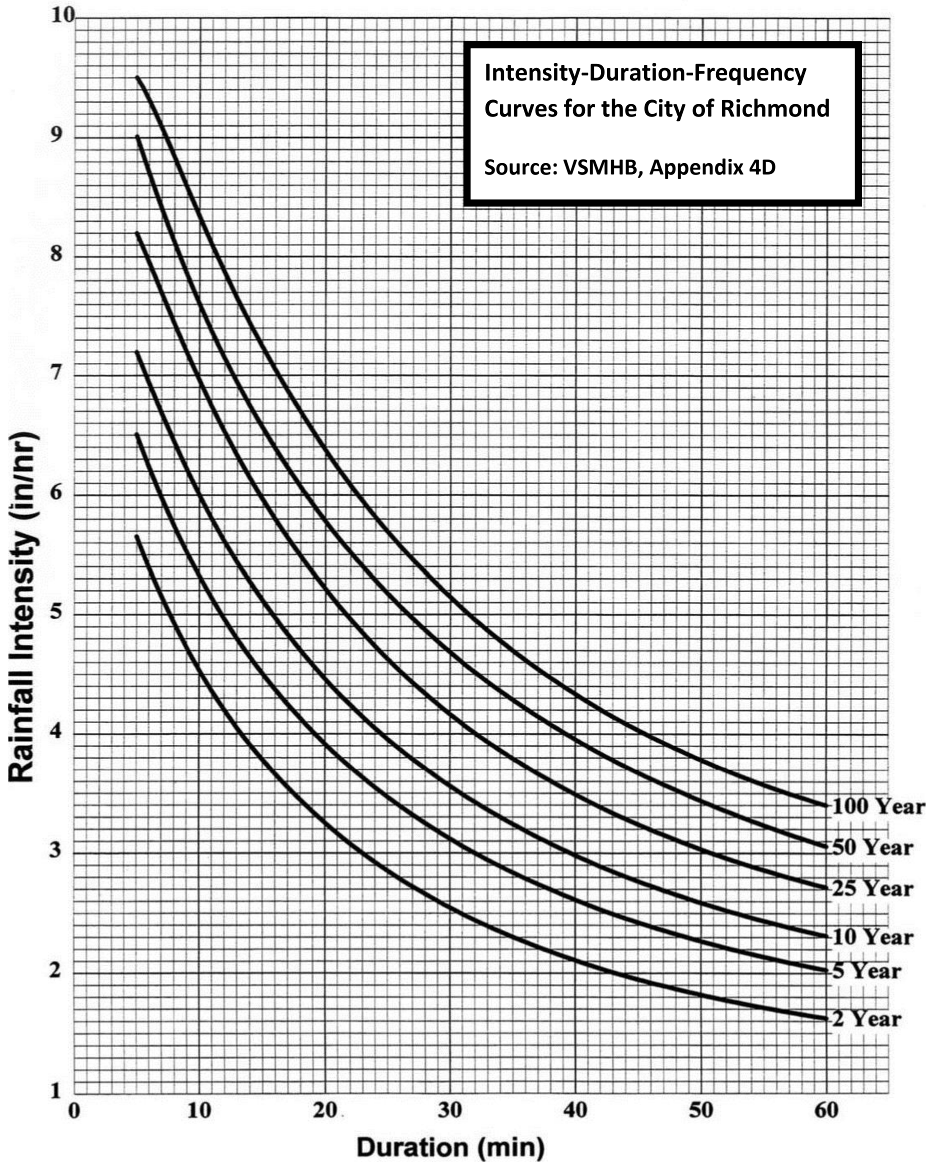

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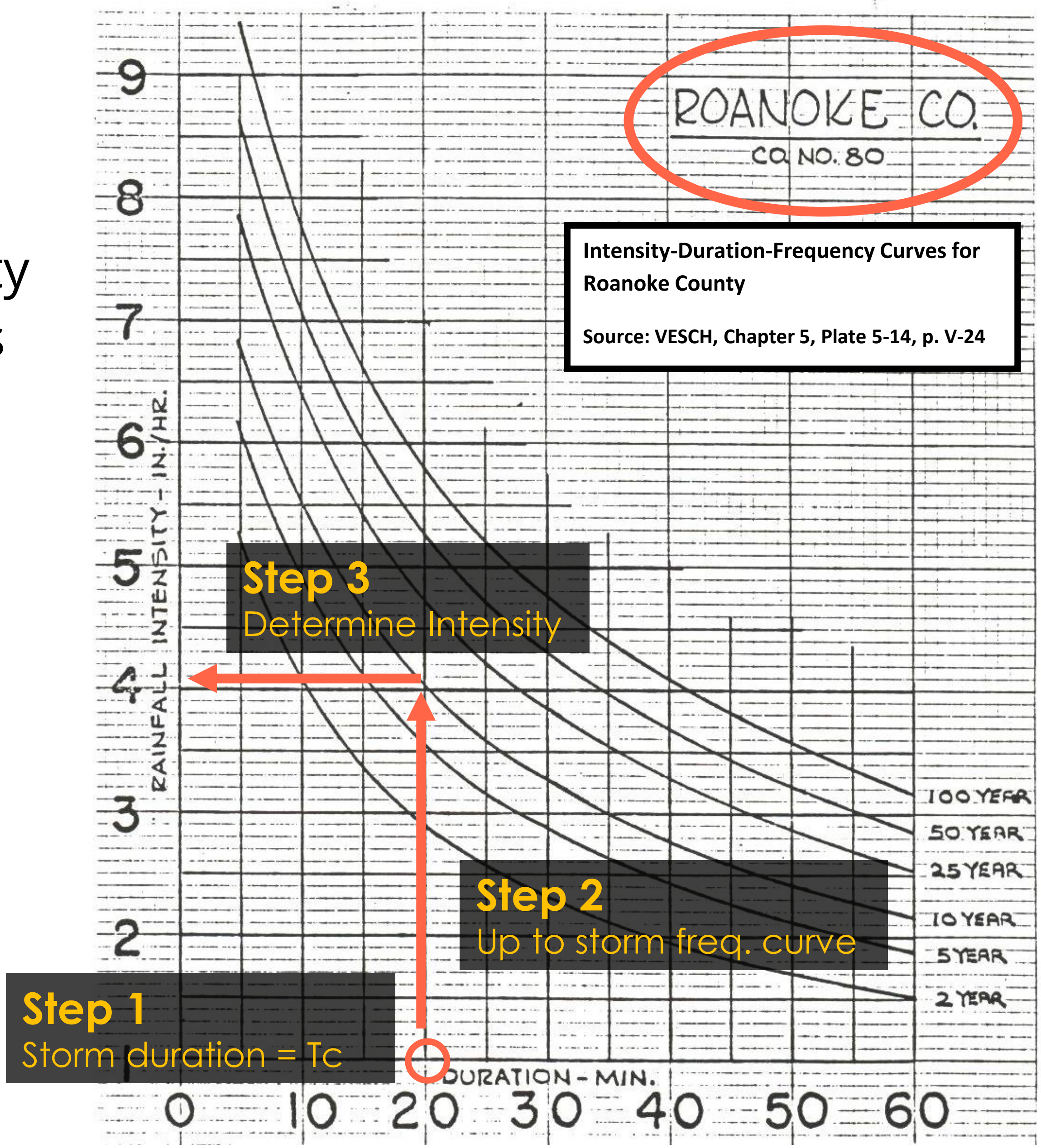
Example:

- Roanoke County
- Tc = 20 minutes
- 10-year storm frequency

Answer:

***i* = 4.1 in/hr**



Rational Method

From previous: A = 10.0 acres, I = 4.1 in/hr, weighted C = 0.39

$$Q = CiA$$

$$Q = 0.39 \times 4.1 \times 10$$

$$Q = 15.99 cfs$$

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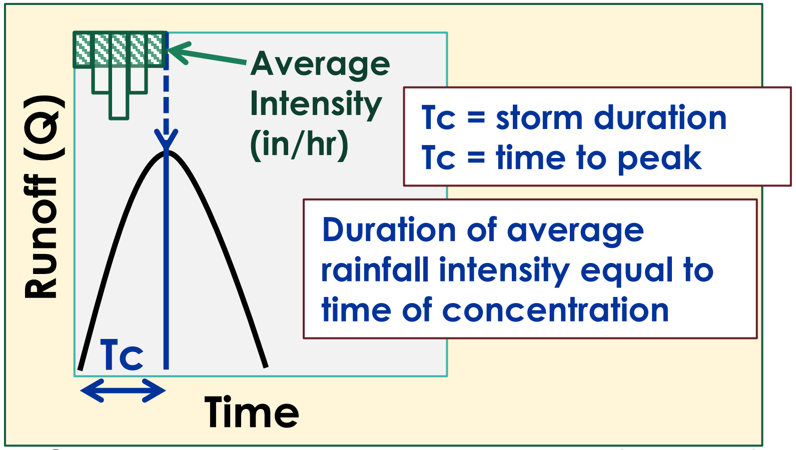
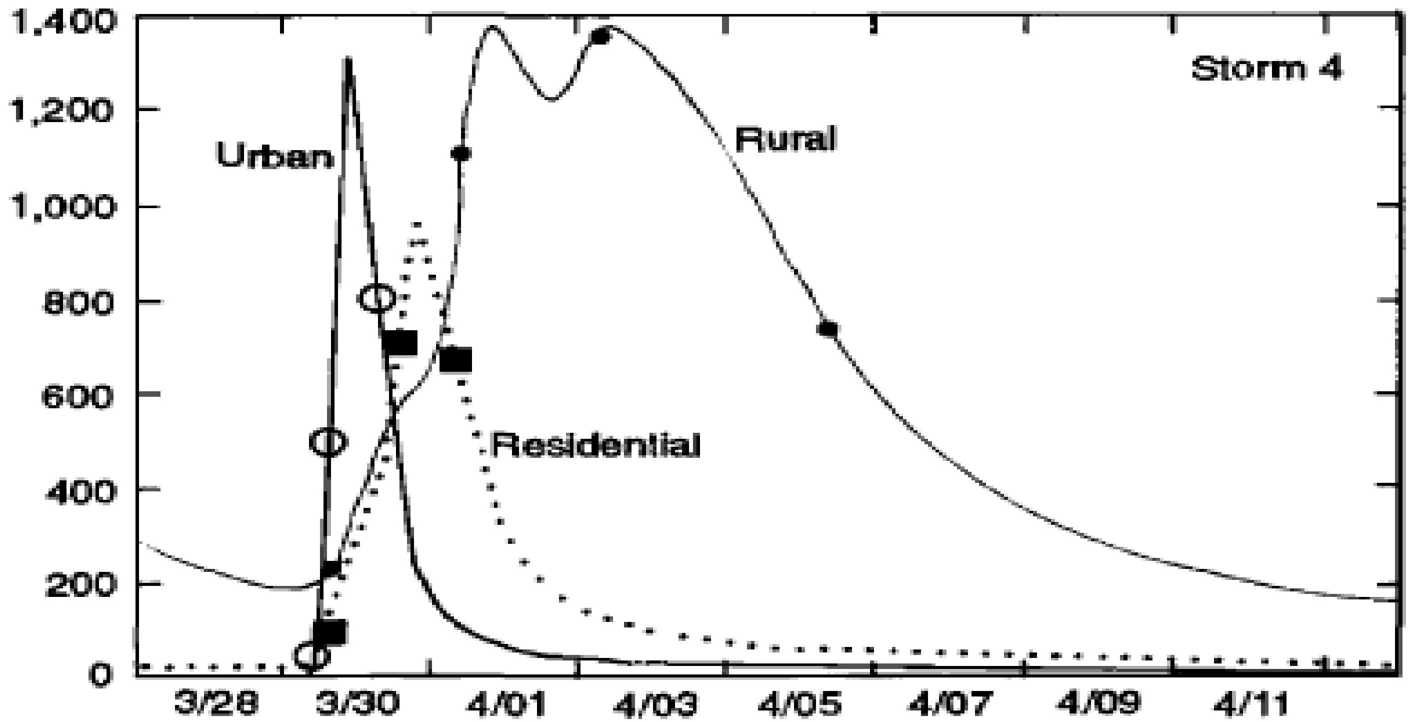
Rational Method: Assumptions and Limitations

- Frequency of rainfall and runoff events similar
- Rainfall
  - uniform intensity
  - duration equal to *Tc*
  - peak discharge of given frequency storm produced by average rainfall intensity
  - over entire area of watershed



Rational Method: Assumptions and Limitations



Accuracy improves with increased imperviousness and decreased watershed size

Rational Method: Assumptions and Limitations

- Peak flow in cubic feet per min. only
- Design of culverts, inlets, etc.
- No Volume
- No IDF or b,d,e constants for 1-year storm
- **Not well suited for VSMP compliance**

Modified Rational Method

Variation for sizing detention facilities

Iterative - Determine rainfall duration that produces **maximum storage volume**

Analyze different durations to find greatest storage volume

(**critical storm duration**)

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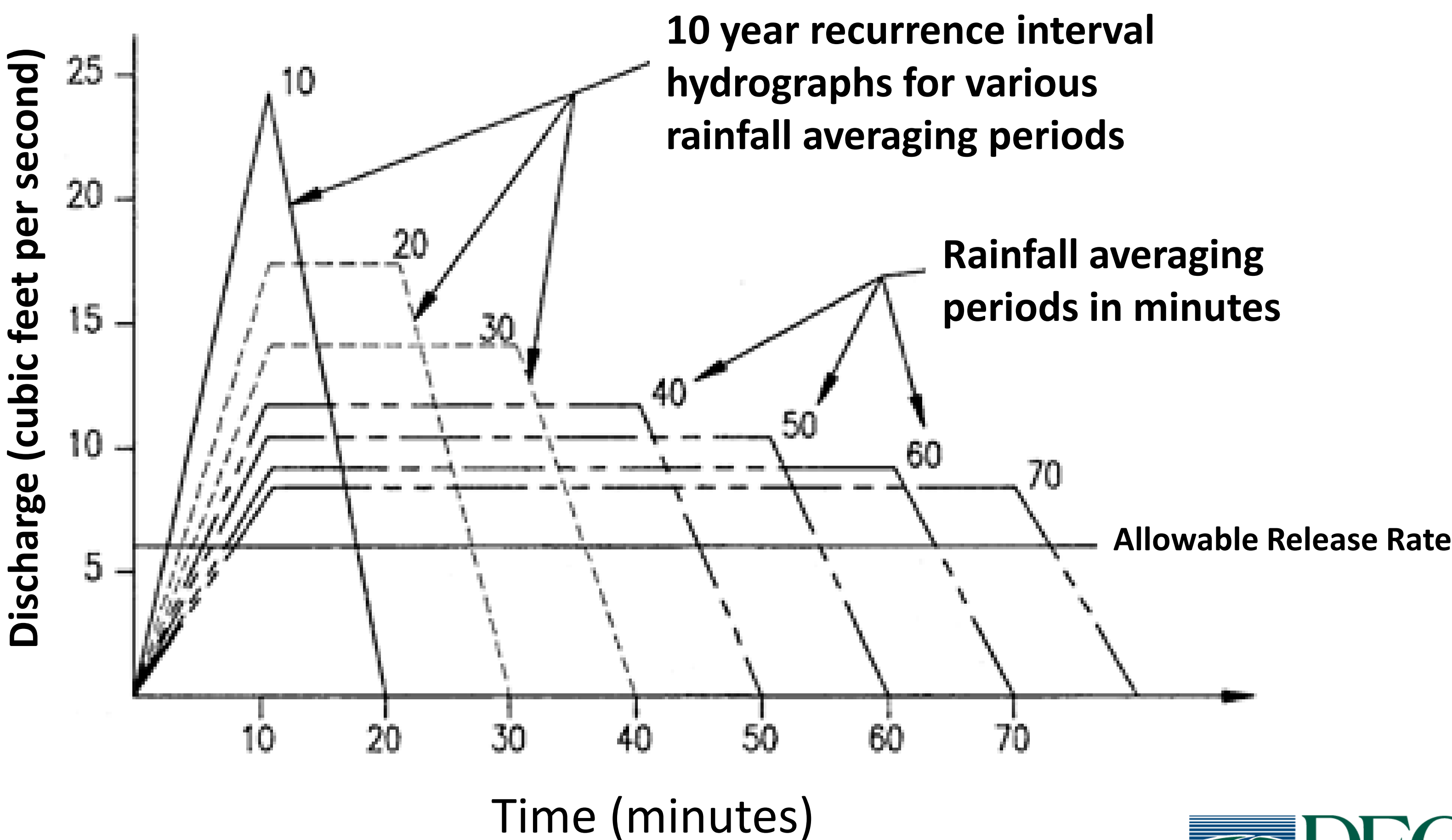
Modified Rational Method

Draft VA SWMH p.. 4-27



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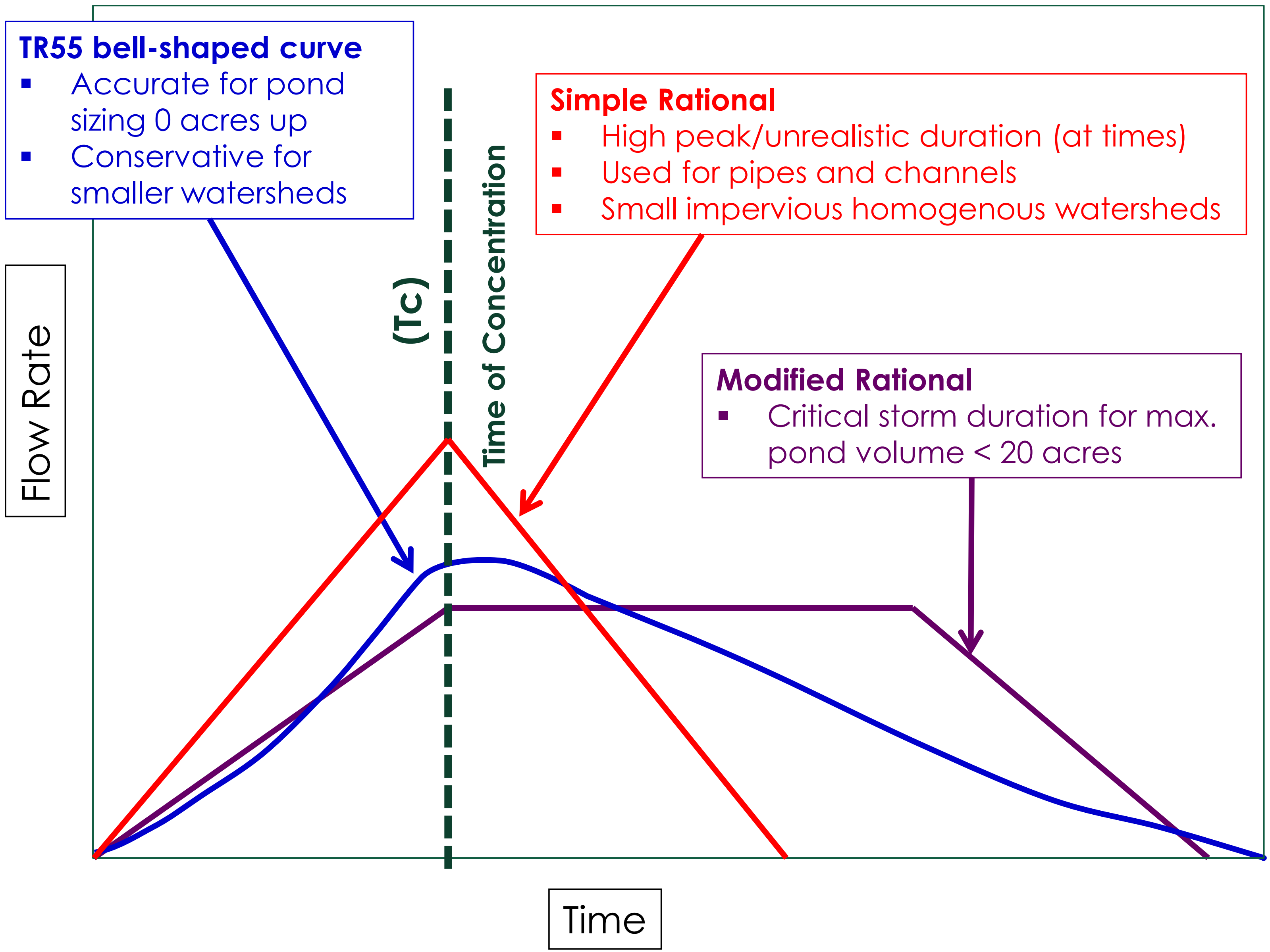
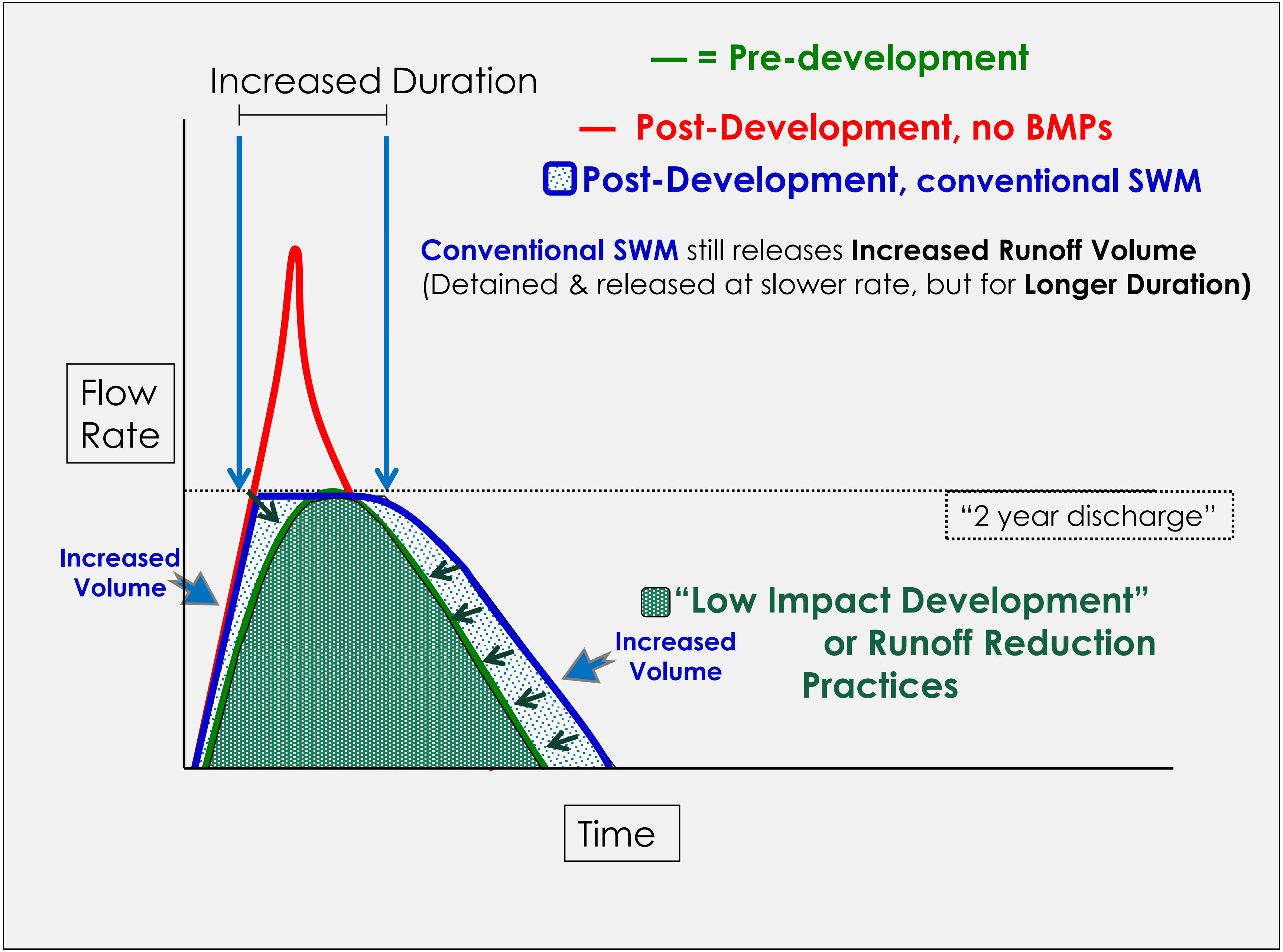
Modified Rational Method

- Design of retention/detention facilities
- Provides volume
- Storm duration corresponds to critical volume
- Not 24 hours duration

INFLOW HYDROGRAPHS





Increased Duration
— = Pre-development
— Post-Development, no BMPs
Post-Development, conventional SWM
Conventional SWM still releases Increased Runoff Volume
(Detained & released at slower rate, but for Longer Duration)
Flow Rate
"2 year discharge"
Increased Volume
"Low Impact Development" or Runoff Reduction Practices
Increased Volume
Time

Questions?